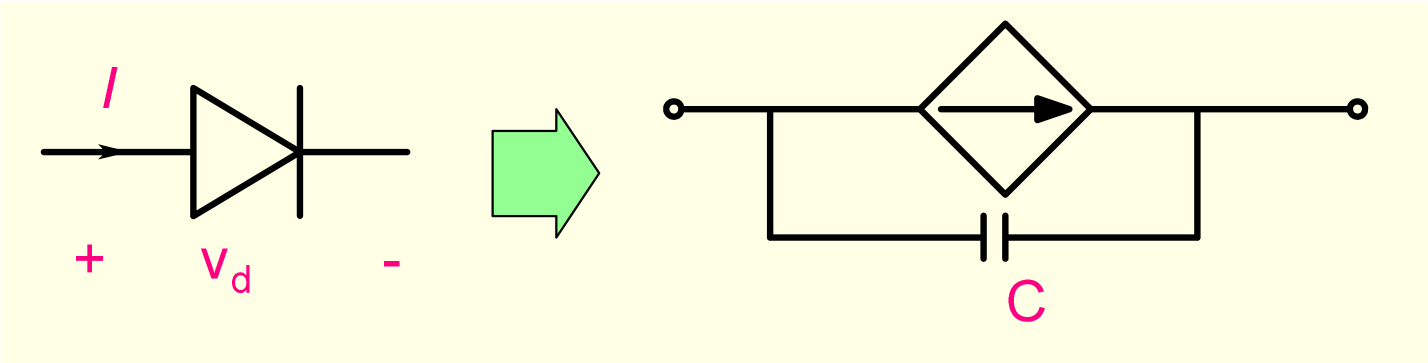
ESC201T : Introduction to Electronics

Lecture 21: Diode Model For Circuit Analysis

B. Mazhari
Dept. of EE, IIT Kanpur

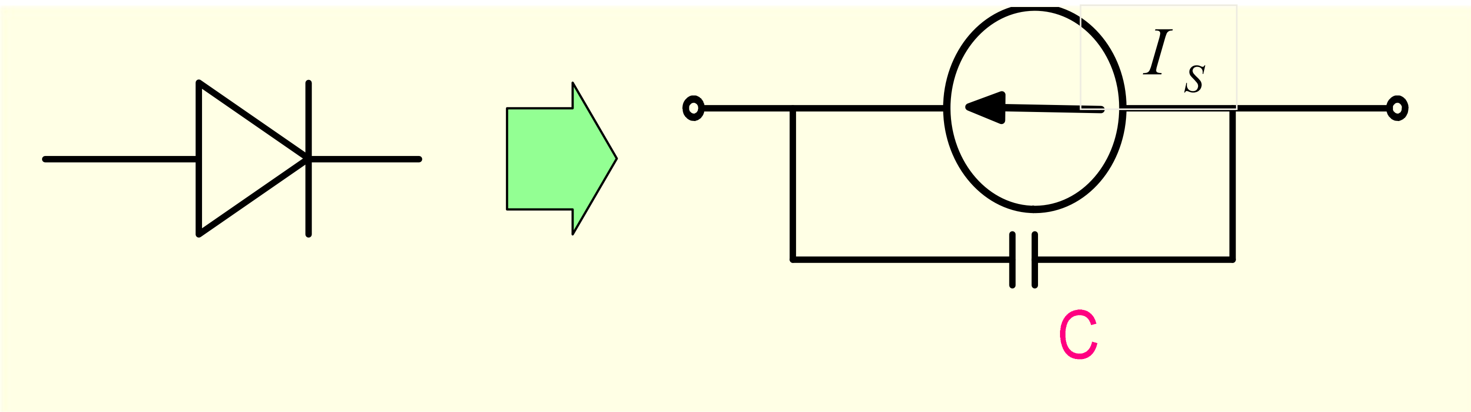
Diode Model: Forward Bias

$$I = I_S \times \{\exp(\frac{V_d}{nV_T}) - 1\}$$



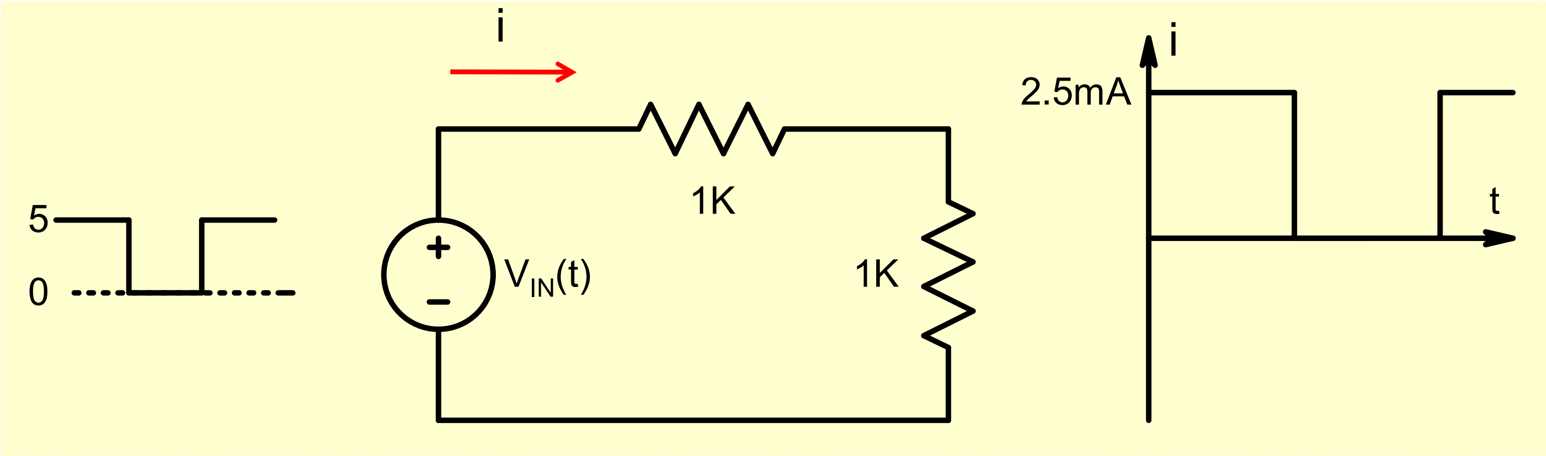
For dc and low frequency ac circuits, the effect of diode capacitance can be neglected

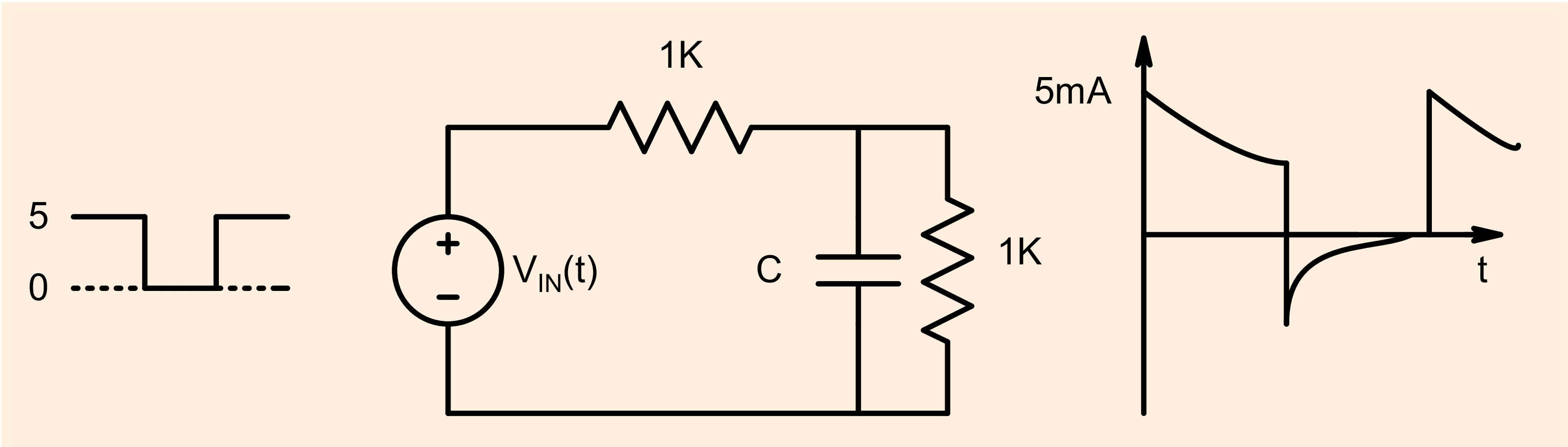
Diode Model: Reverse Bias

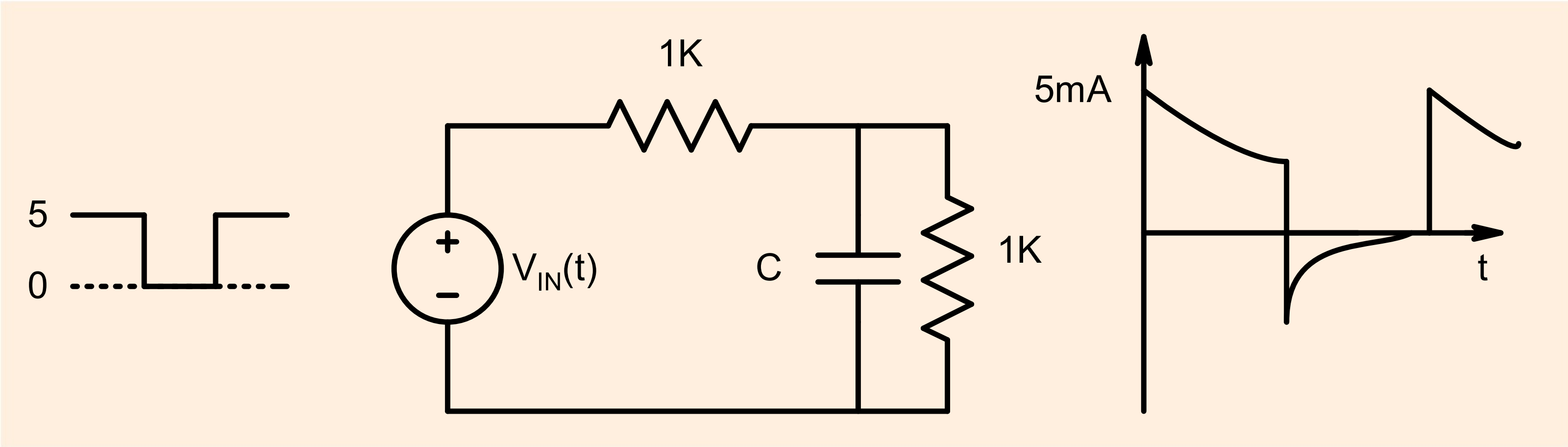


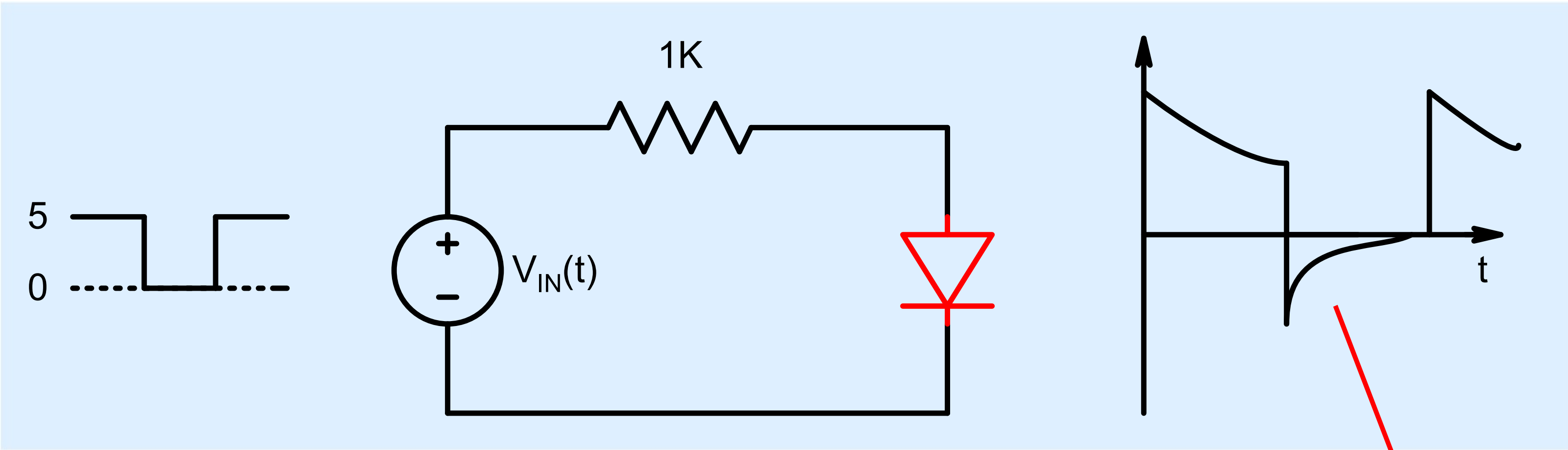
Because of capacitance, a diode even though reverse biased, can carry significant current momentarily

Example



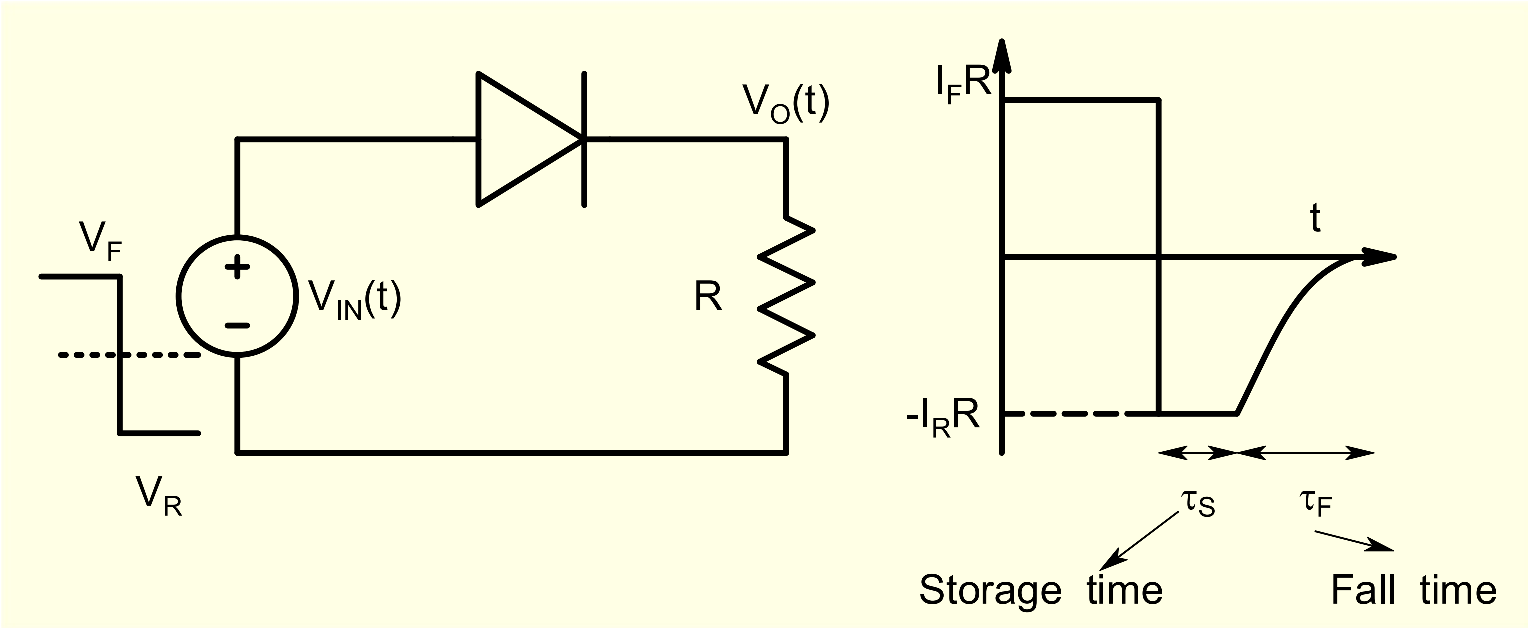






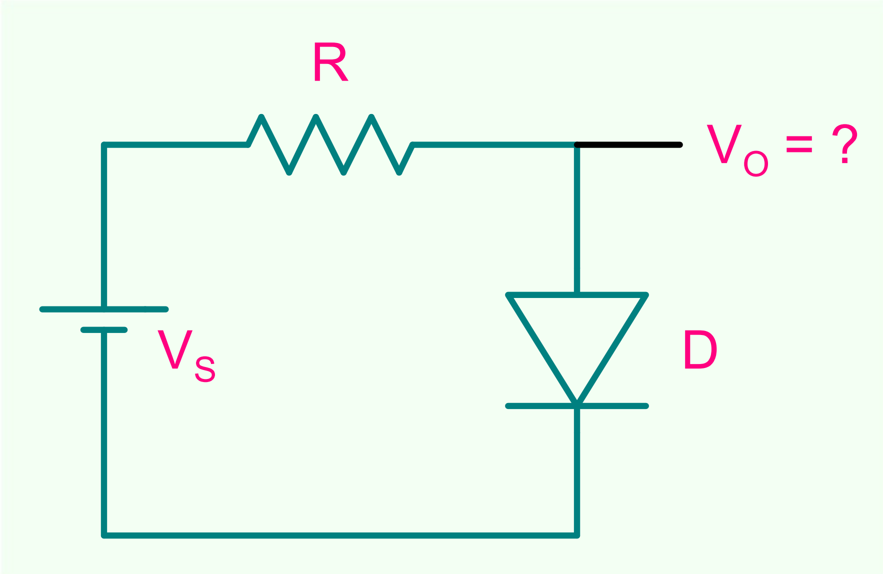
Current in reverse direction

Transient Response



Diode does not switch off instantly but remains conducting for a period called reverse recovery time which is sum of storage and fall delay times..

Analysis using non-linear diode model is not easy



$$V_S = IR + V_O \quad (1)$$

$$I = I_S \times \{\exp(\frac{V_O}{nV_T}) - 1\} \quad (2)$$

$$\Rightarrow \quad V_O = nV_T \times \ln(\frac{\mathrm{I}}{\mathrm{I_S}} + 1) \quad (3)$$

$$\Rightarrow \quad V_S = IR + nV_T \times \ln(\frac{\mathrm{I}}{\mathrm{I_S}} + 1) \quad (4)$$

Iterative Method:

$$V_S = IR + V_O \quad (1)$$

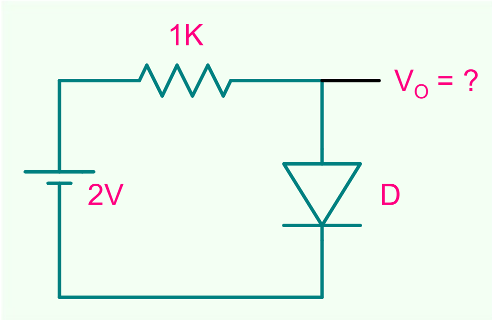
$$I = I_S \times \{\exp(\frac{V_O}{nV_T}) - 1\} \quad (2)$$

Assume $V_O = 0.6\text{V}$

Calculate $I = \dfrac{V_S - V_O}{R}$

Re-calculate $V_O = nV_T \times \ln(\mathrm{I}/\mathrm{I_S} + 1)$

Convergence: $\dfrac{\Delta I}{I} \leq \varepsilon$



$$I = I_S \times \{\exp(\frac{V}{V_T}) - 1\}$$

$$I_S = 2 \times 10^{-15}\ A$$

$$V_T = kT\ /\ q \cong 26\ mV \text{ at T} = 300\text{K}$$

Assume V_O

$$I = \frac{V_S - V_O}{R}$$

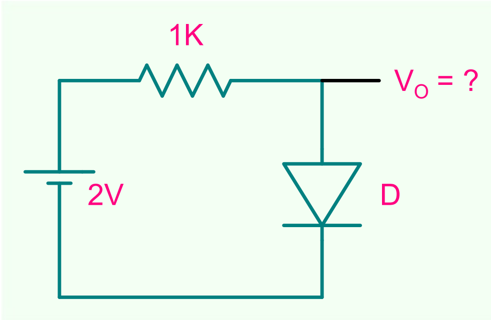
$$V_O = nV_T \times \ln(I/I_S + 1)$$

$V_O = 0.5$ $\quad$ $V_O = 0.711$ $\quad$ $V_O = 0.707$

$I = 1.5 \times 10^{-3}$ $\quad$ $I = 1.289 \times 10^{-3}$ $\quad$ $I = 1.293 \times 10^{-3}$

$V_O = 0.711$ $\quad$ $V_O = 0.707$ $\quad$ $V_O = 0.707$

CONVERGENCE



$$I = I_S \times \{\exp(\frac{V}{V_T}) - 1\}$$

$$I_S = 2 \times 10^{-15}\ A$$

$$V_T = kT\ /\ q \cong\ 26\ mV \quad \text{at}\ \ \mathrm{T} = 300\mathrm{K}$$

Assume V_O

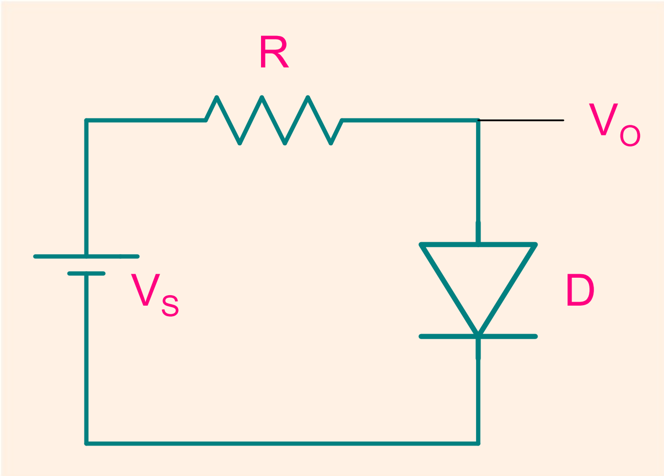
$$I = \frac{V_S - V_O}{R}$$

$$V_O = nV_T \times \ln(\mathrm{I}/\mathrm{I_S} + 1)$$

$V_O = 1.0$	$V_O = 0.7$	$V_O = 0.707$
$I = 1.0 \times 10^{-3}$	$I = 1.3 \times 10^{-3}$	$I = 1.293 \times 10^{-3}$
$V_O = 0.7$	$V_O = 0.707$	$V_O = 0.707$

CONVERGENCE to the same Result

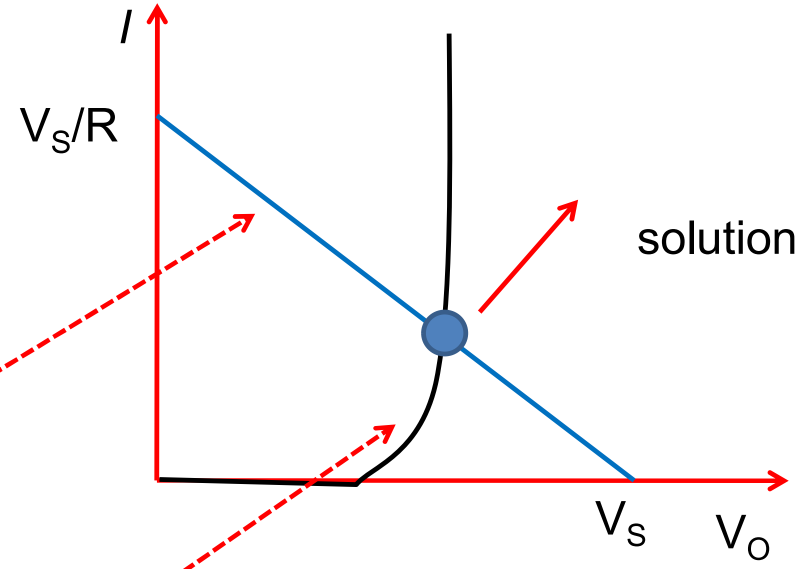
Graphical Method: Method of Load Line

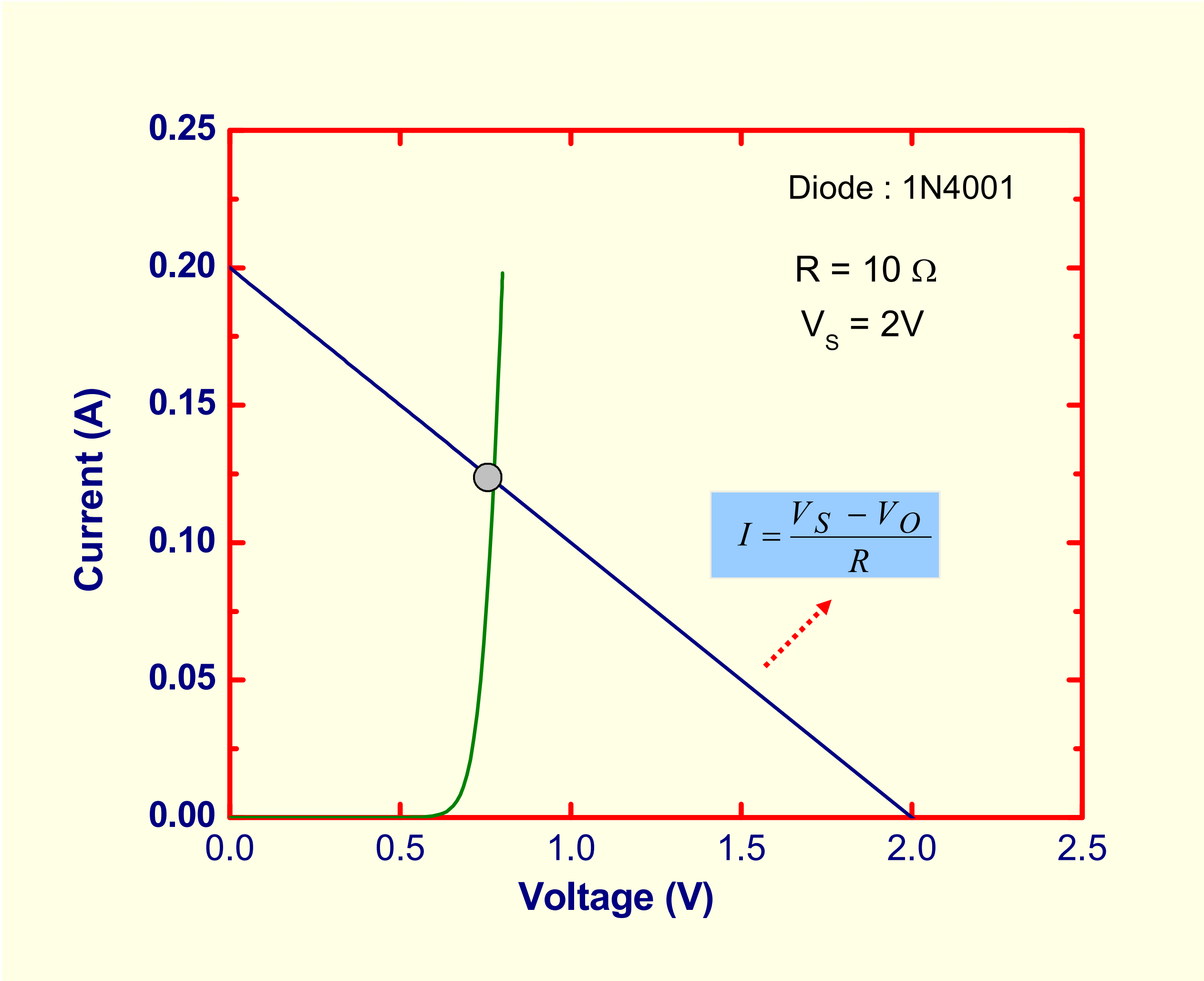


$$V_S = I \times R + V_O$$

$$I = \frac{V_S - V_O}{R}$$

$$I = I_S \times \{\exp(\frac{V_O}{nV_T}) - 1\}$$





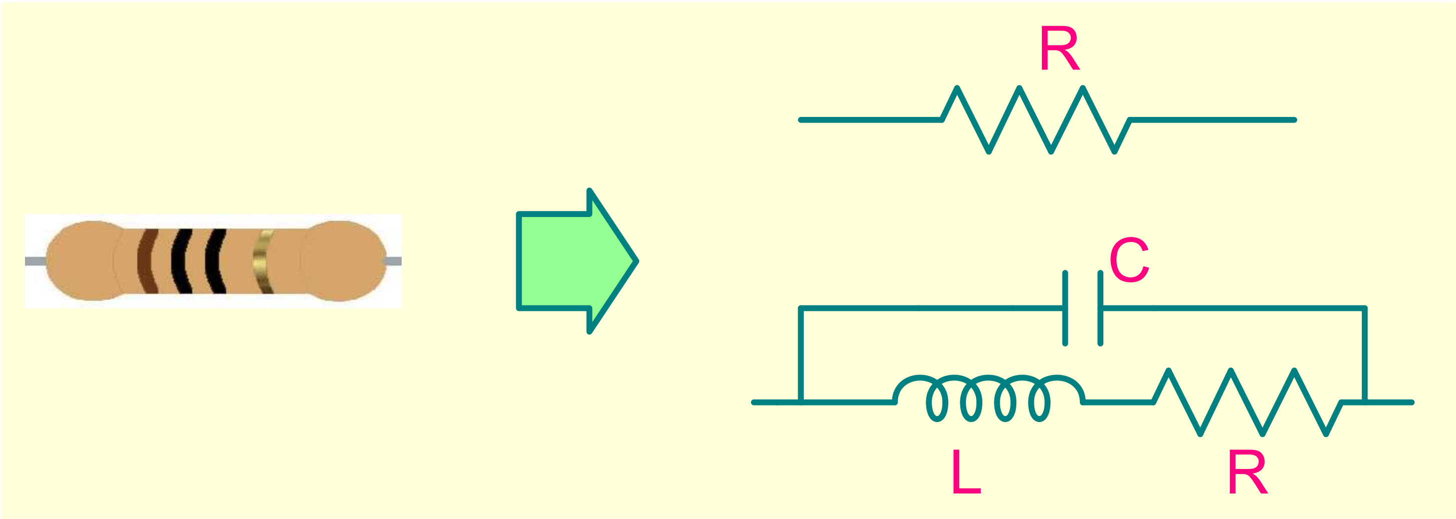
$V_O = 0.77V$; I = 0.12A

For hand analysis of circuits, we need simpler models!

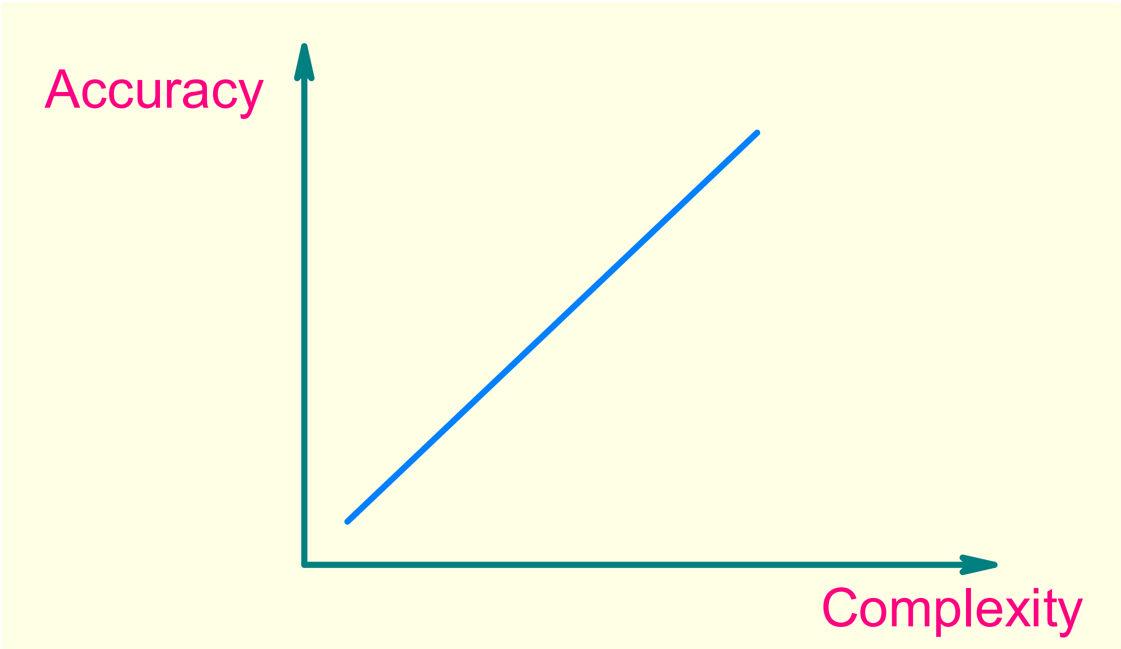
What is a model?

"A model is a representation for a PURPOSE"

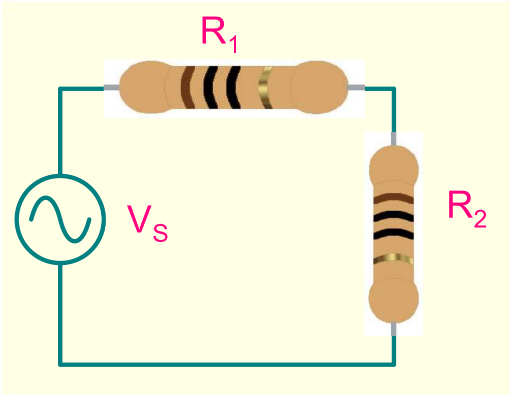
Depending on the purpose, an element can have several different models

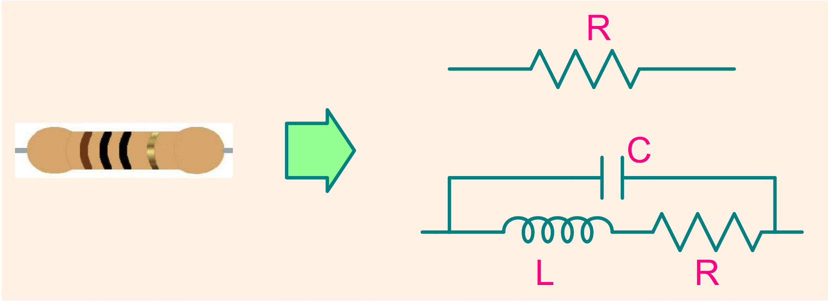


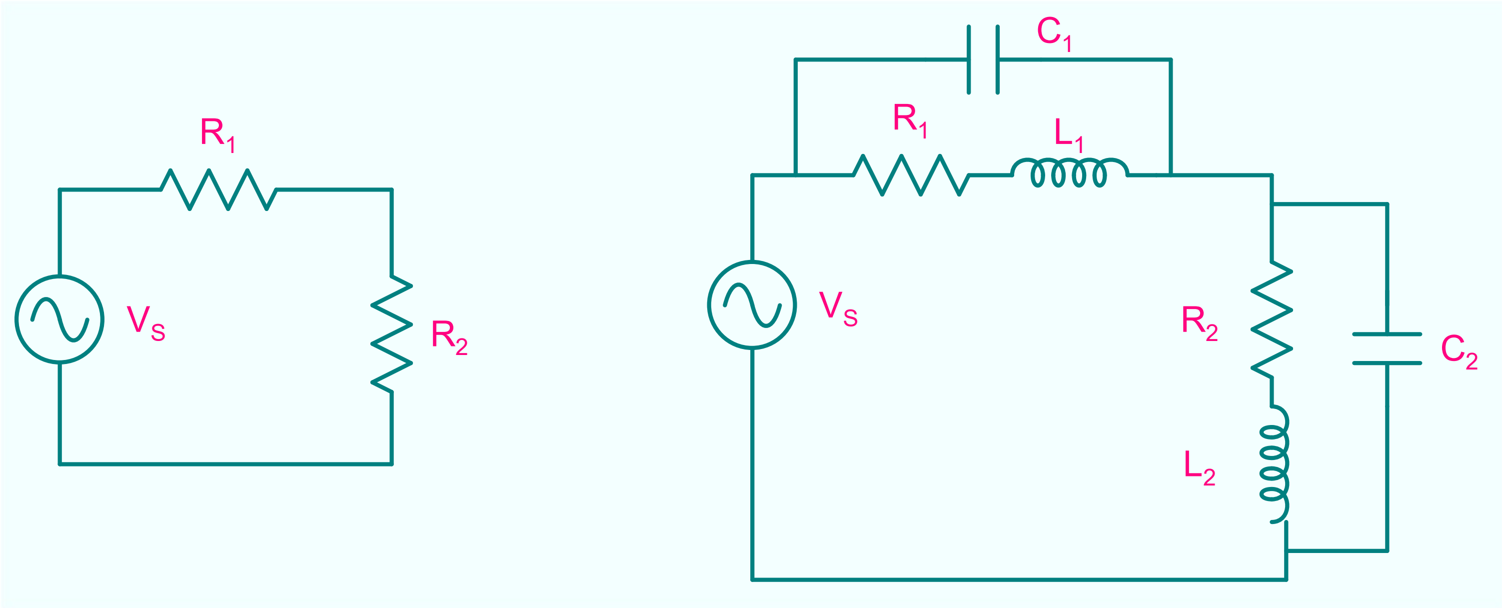
In general, there is a tradeoff between Accuracy and Complexity of model



What is the use of a less accurate model?

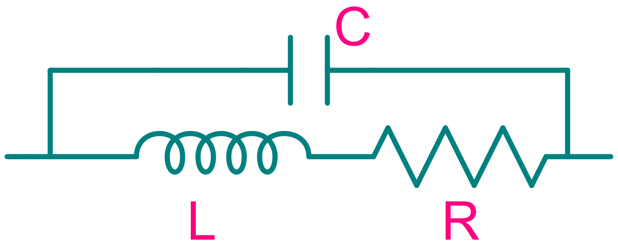






1. A simpler model makes analysis easier

$$\frac{V_2}{V_S} = \frac{R_2}{R_1 + R_2}$$



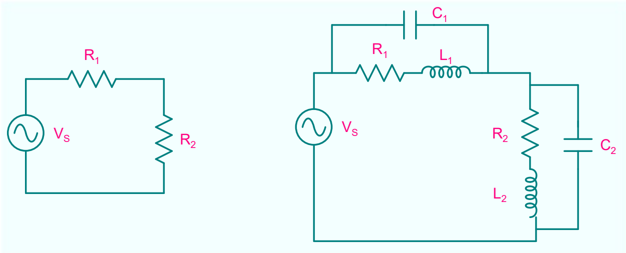
$$\frac{V_2}{V_S} = \frac{R_2 + j\omega L_2}{R_2 + j\omega L_2 + (R_1 + j\omega L_1)\dfrac{j\omega C_2 R_2 - \omega^2 L_2 C_2 + 1}{j\omega C_1 R_1 - \omega^2 L_1 C_1 + 1}}$$

The results of analysis are easier to understand

3. The results of analysis can be used easily to carry out the design

Design the circuit such that :

$$\frac{V_2}{V_S} = 0.2 \quad \text{at 1kHz frequency}$$



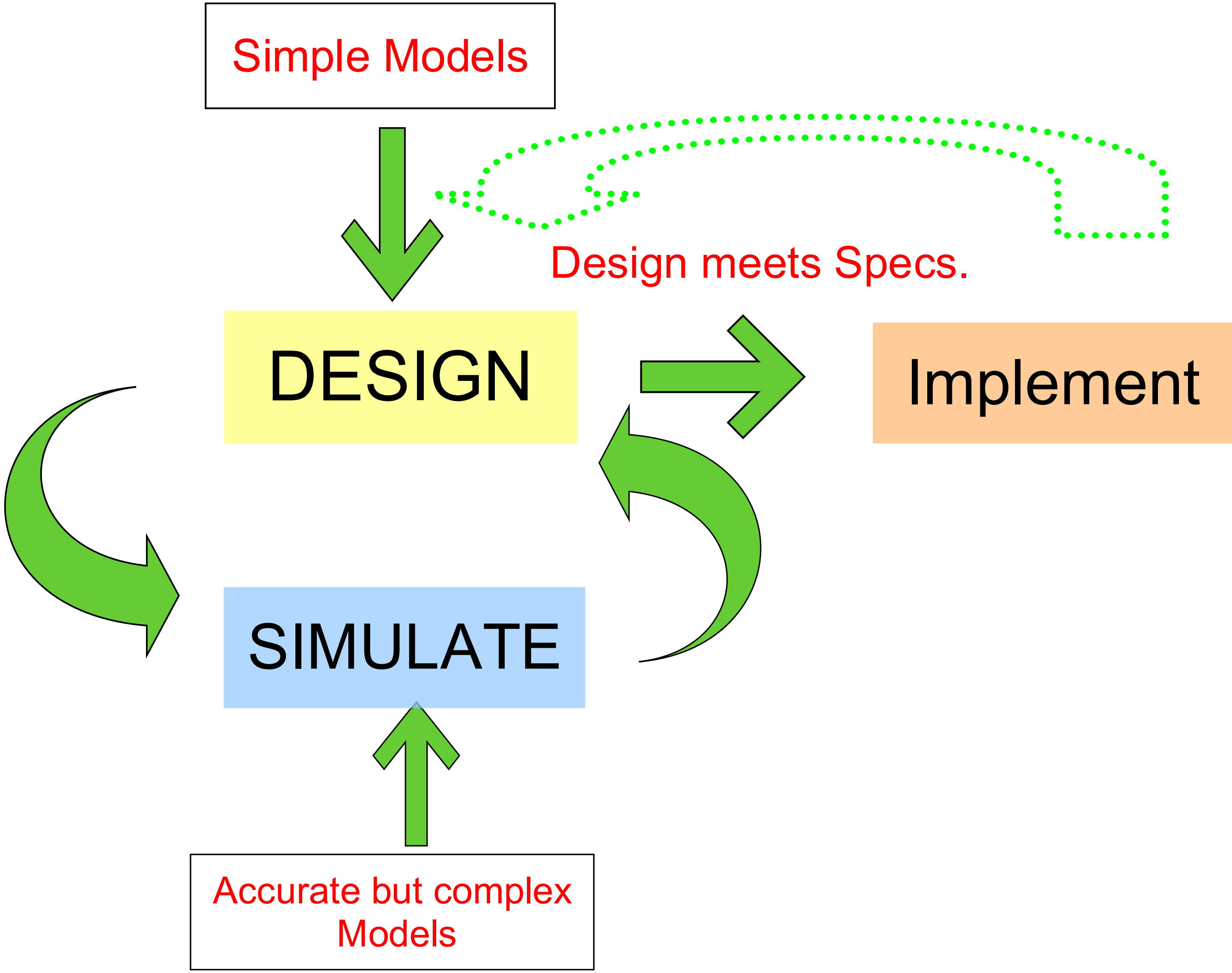
$$\frac{R_2}{R_1 + R_2} = 0.2$$

$$\Rightarrow \quad \frac{R_1}{R_2} = 4$$

Try doing the design with this expression:

$$\frac{V_2}{V_S} = \frac{R_2 + j\omega L_2}{R_2 + j\omega L_2 + (R_1 + j\omega L_1)\dfrac{j\omega C_2 R_2 - \omega^2 L_2 C_2 + 1}{j\omega C_1 R_1 - \omega^2 L_1 C_1 + 1}}$$

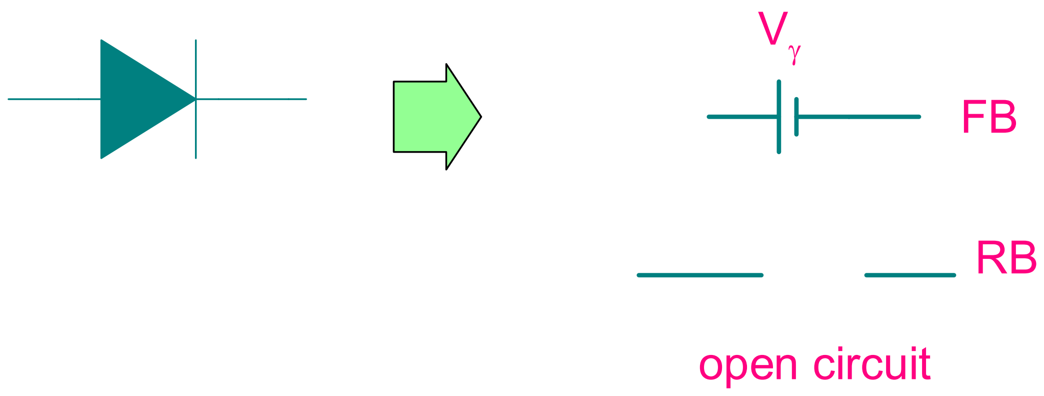
Role of simple model in design cycle



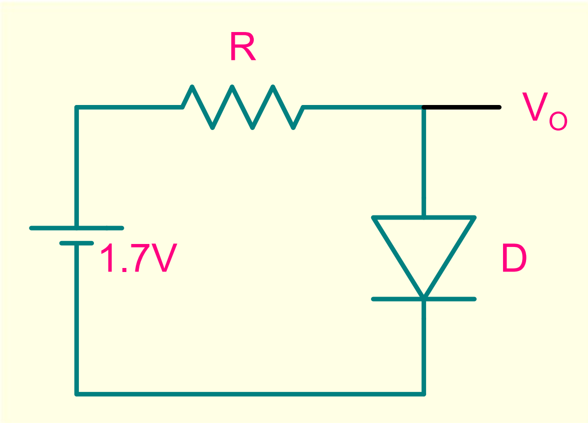
•Analysis using a non-linear diode model is relatively difficult and time consuming.

•It also does not give a symbolic expression that can provide insight and help in the design of the circuit.

Need SIMPLER and LINEAR Device Models



What should we take as diode drop?.....0.7V?



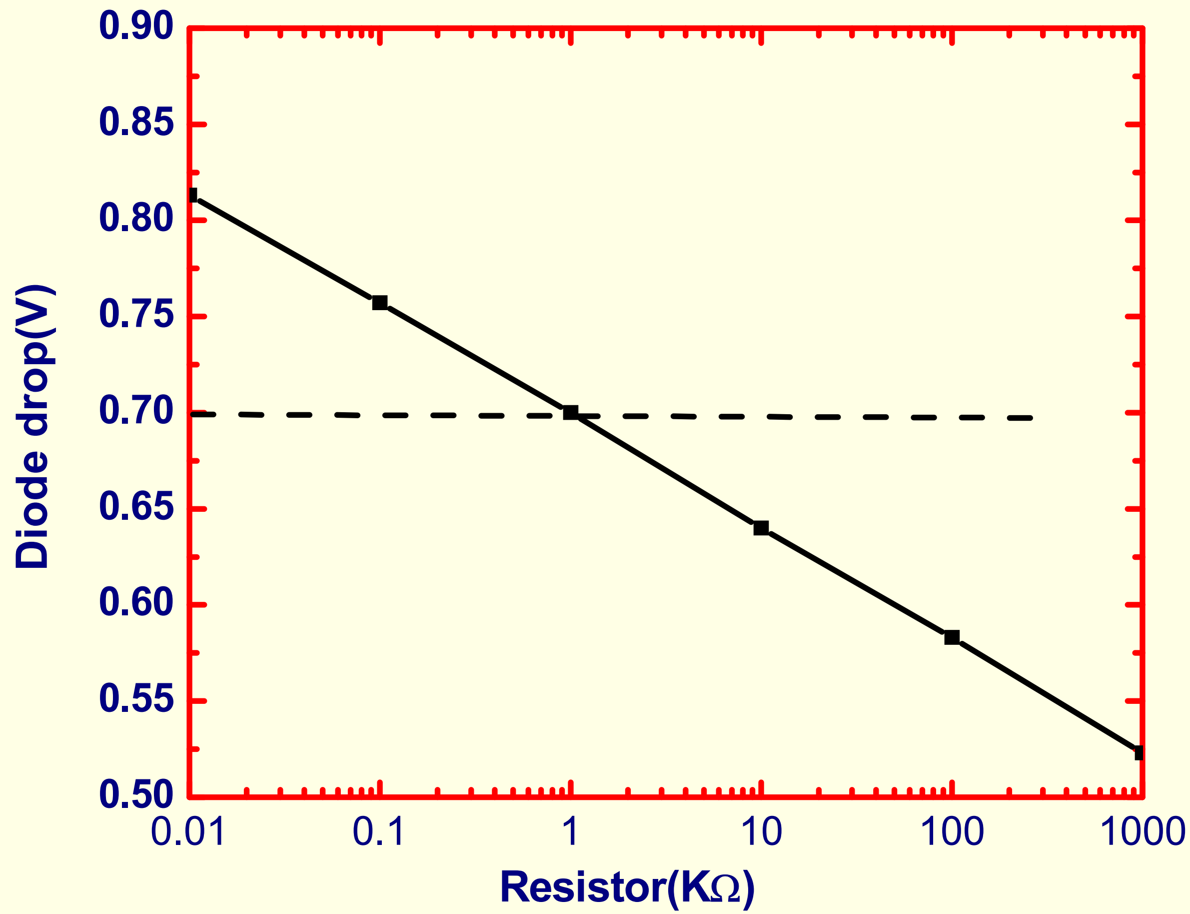
$$I = I_S \times \{\exp(\frac{V}{V_T}) - 1\}$$

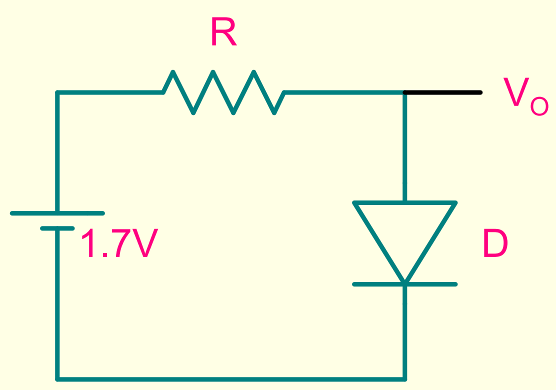
$$I_S = 2 \times 10^{-15} \; A$$

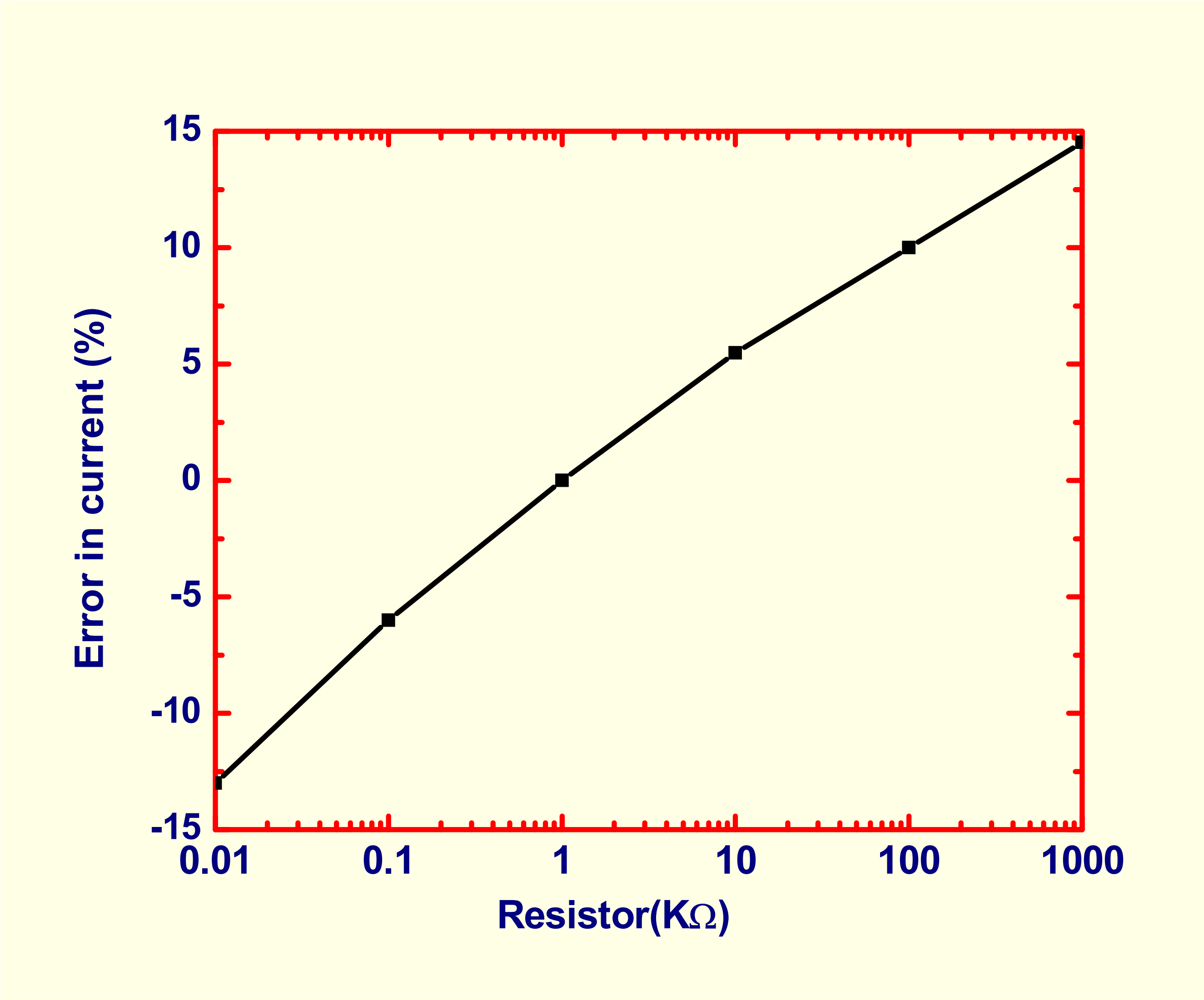
$$V_T = kT / q \cong 26\, mV \quad \text{at T} = 300\text{K}$$

$$R: \; 10\Omega \rightarrow 1M\Omega$$

Simple 0.7V model would predict: $I = \frac{1}{R}$


0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.01
0.1
1
10
100
1000
Diode drop(V)
Resistor(KΩ)

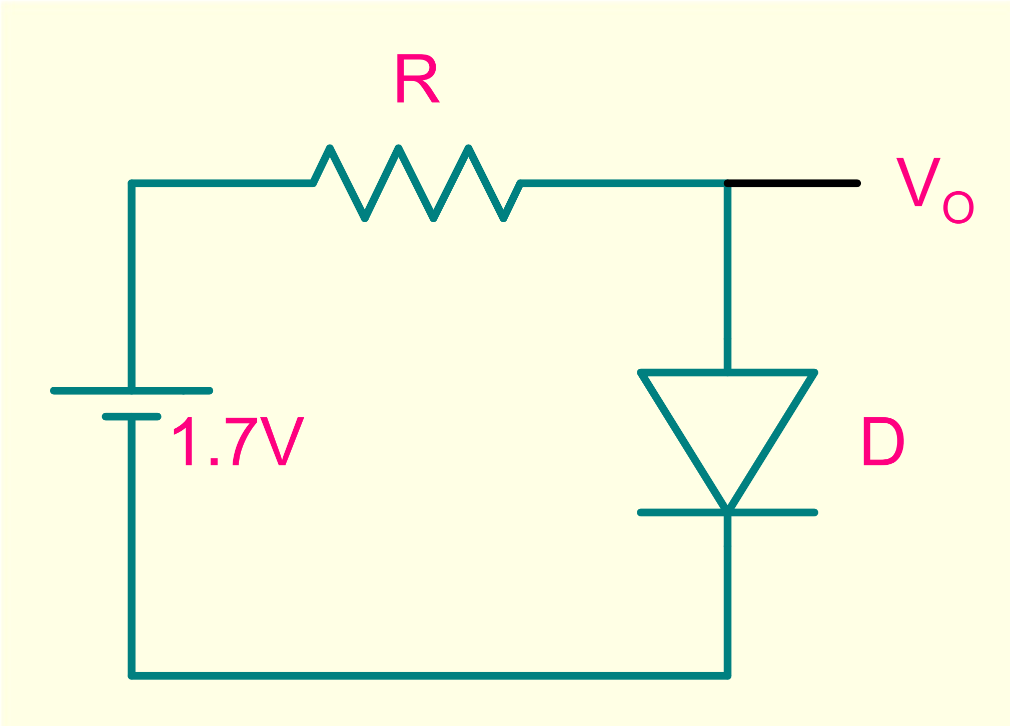

R
V_O
1.7V
D



15
10
5
0
-5
-10
-15
0.01
0.1
1
10
100
1000
Error in current (%)
Resistor(KΩ)

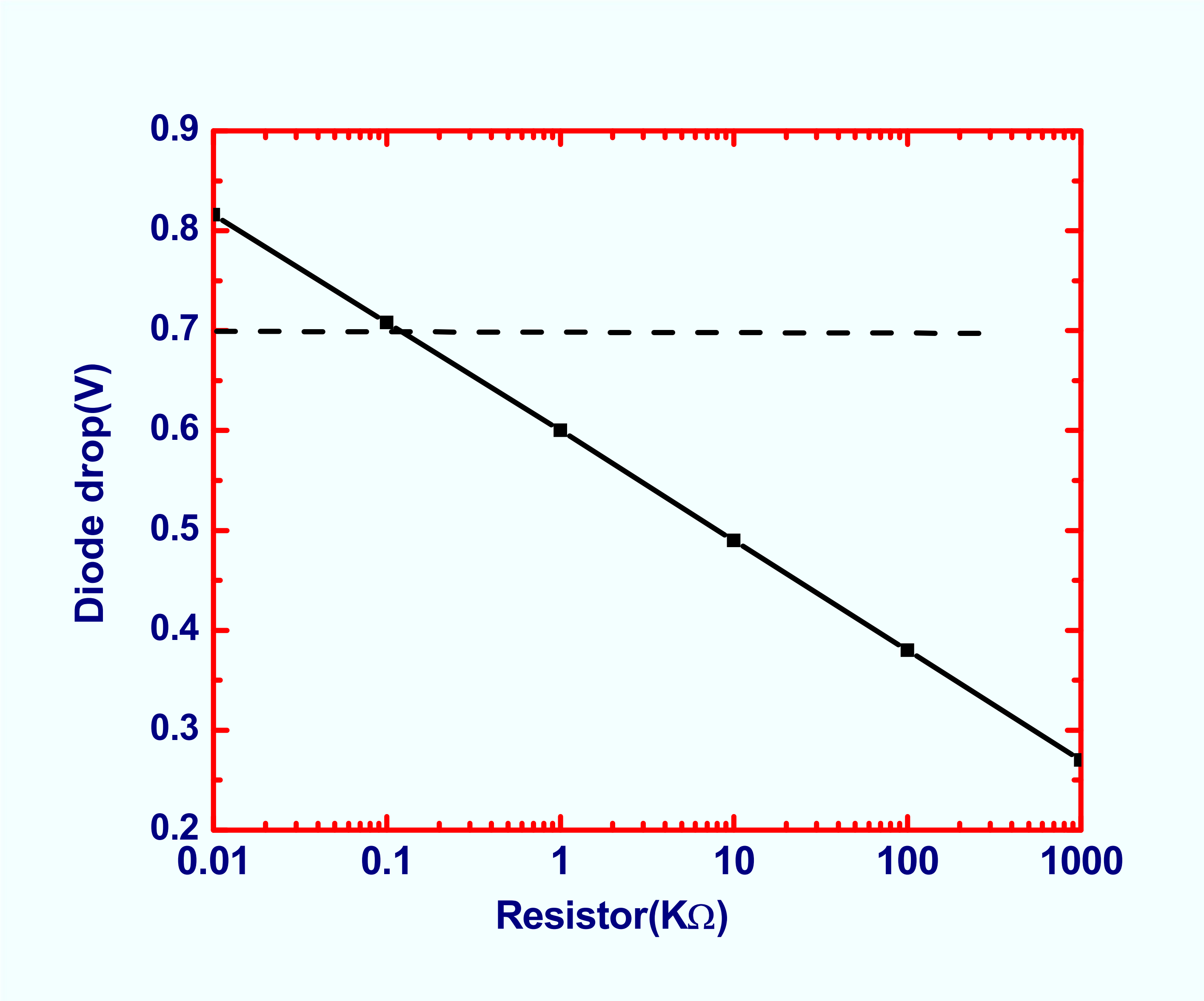
(100mA - 1μA)

Different Diode: ~1N4148

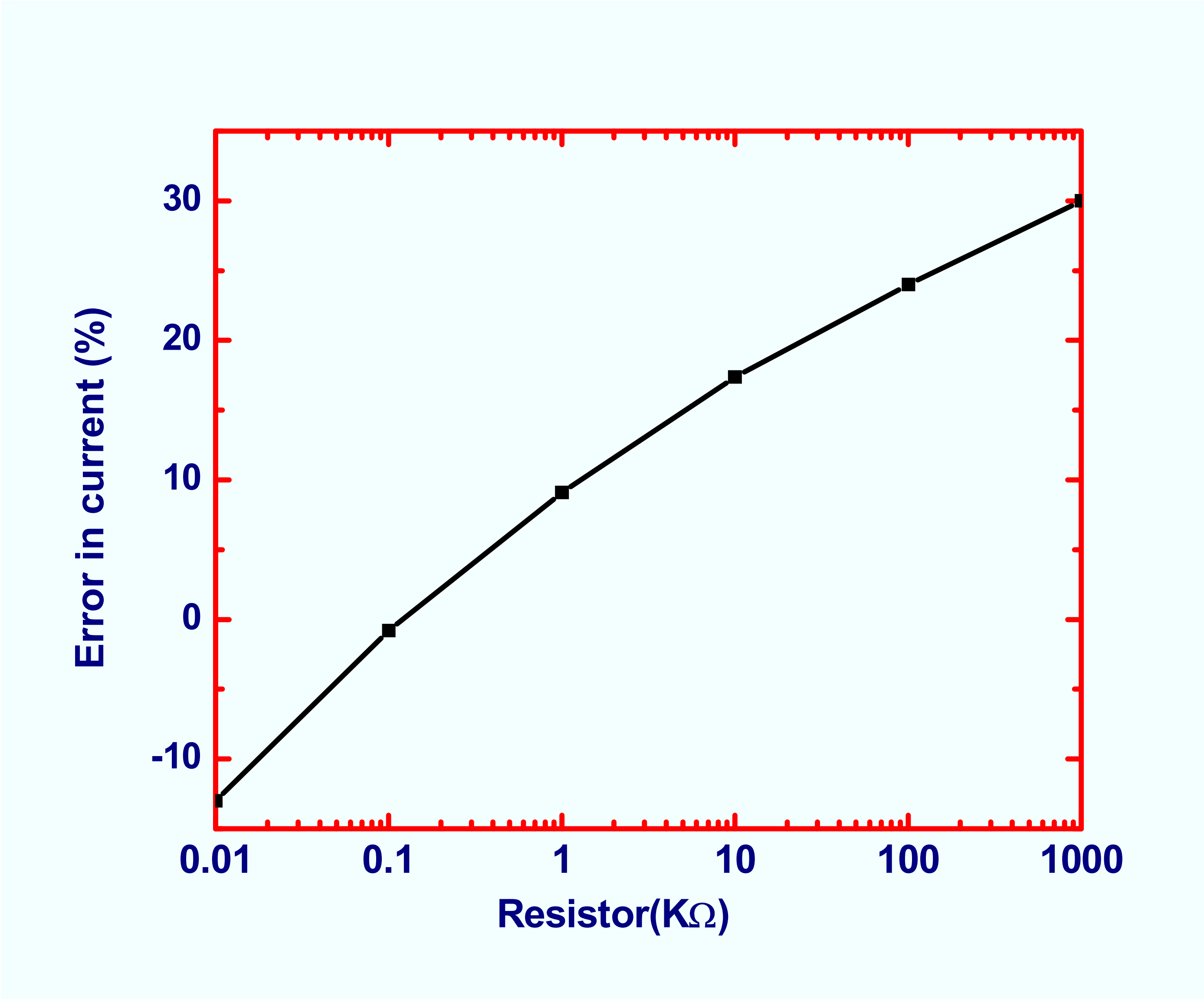


$$I = I_S \times \{\exp(\frac{V}{nV_T}) - 1\}$$

$$I_S = 5.9 \times 10^{-9} A \; ; n = 1.91$$

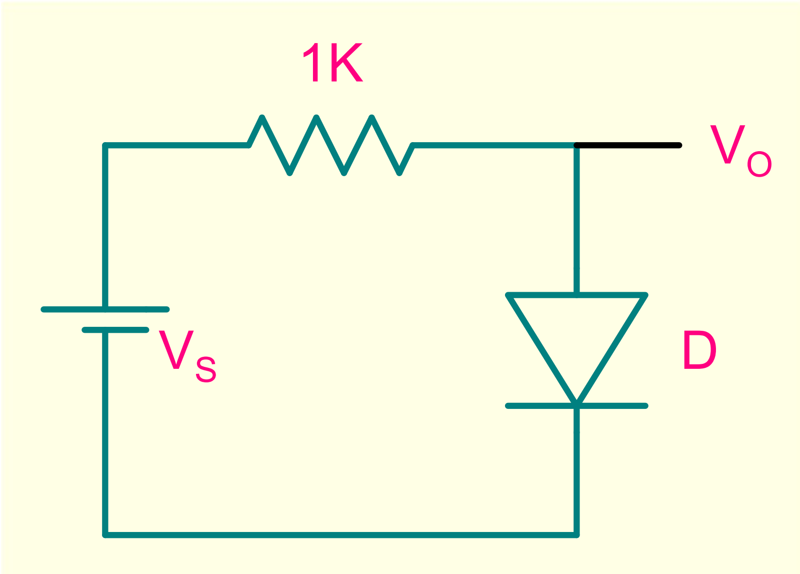


0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
Diode drop(V)
0.01
0.1
1
10
100
1000
Resistor(KΩ)



30
20
10
0
-10
Error in current (%)
0.01
0.1
1
10
100
1000
Resistor(KΩ)

Constant diode voltage approximation becomes worse as applied voltage approaches the diode drop !



$$I = \frac{V_S - V_D}{R}$$

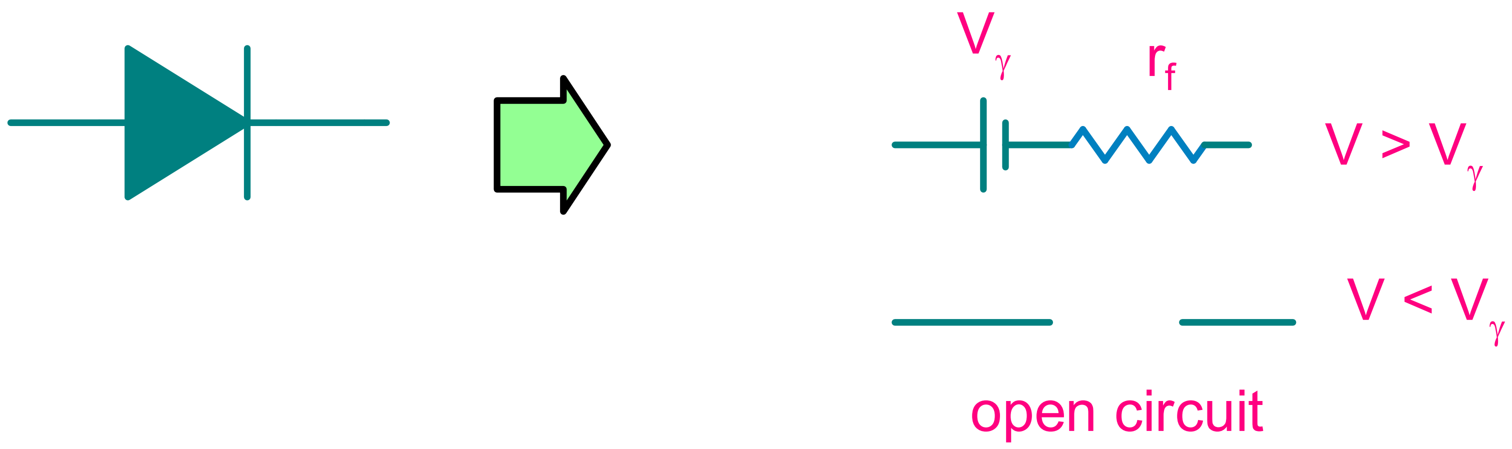
$$\Delta I = -\frac{\Delta V_D}{R}$$

$$\frac{\Delta I}{I} = -\left(\frac{\Delta V_D}{V_S - V_D}\right)$$

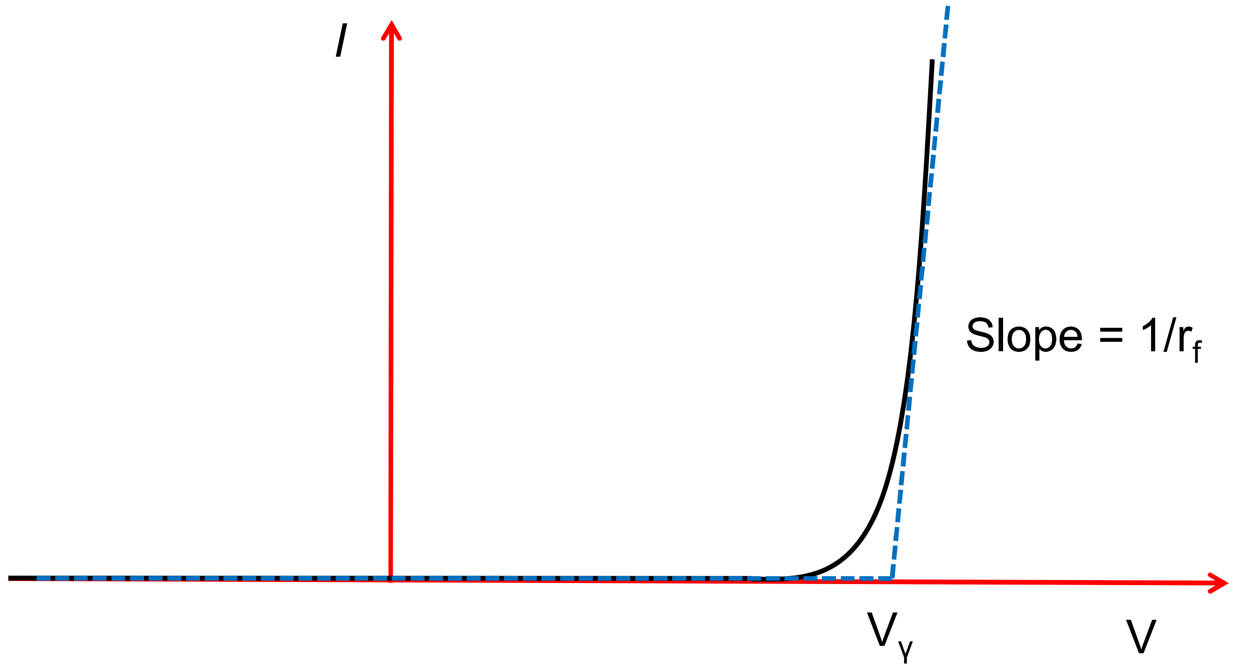
As $\mathbf{V}_s$ approaches $\mathrm{V_D} \rightarrow \left(\frac{\Delta I}{I}\right)$ increases

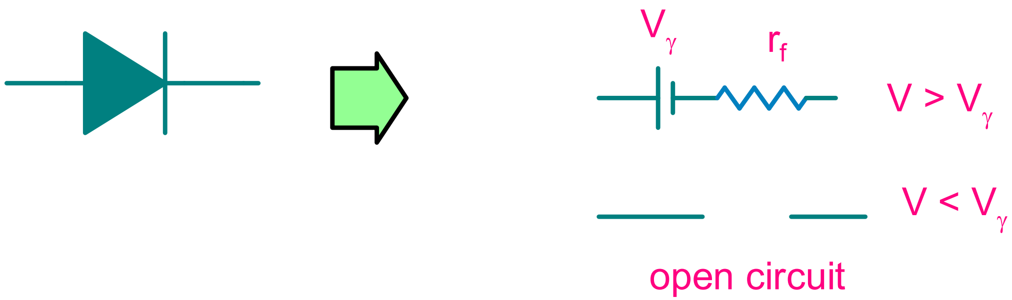
Error was ~9% with 1.7 V but 63% with 0.8V supply

A better Diode Model



Piece-Wise Linear Model



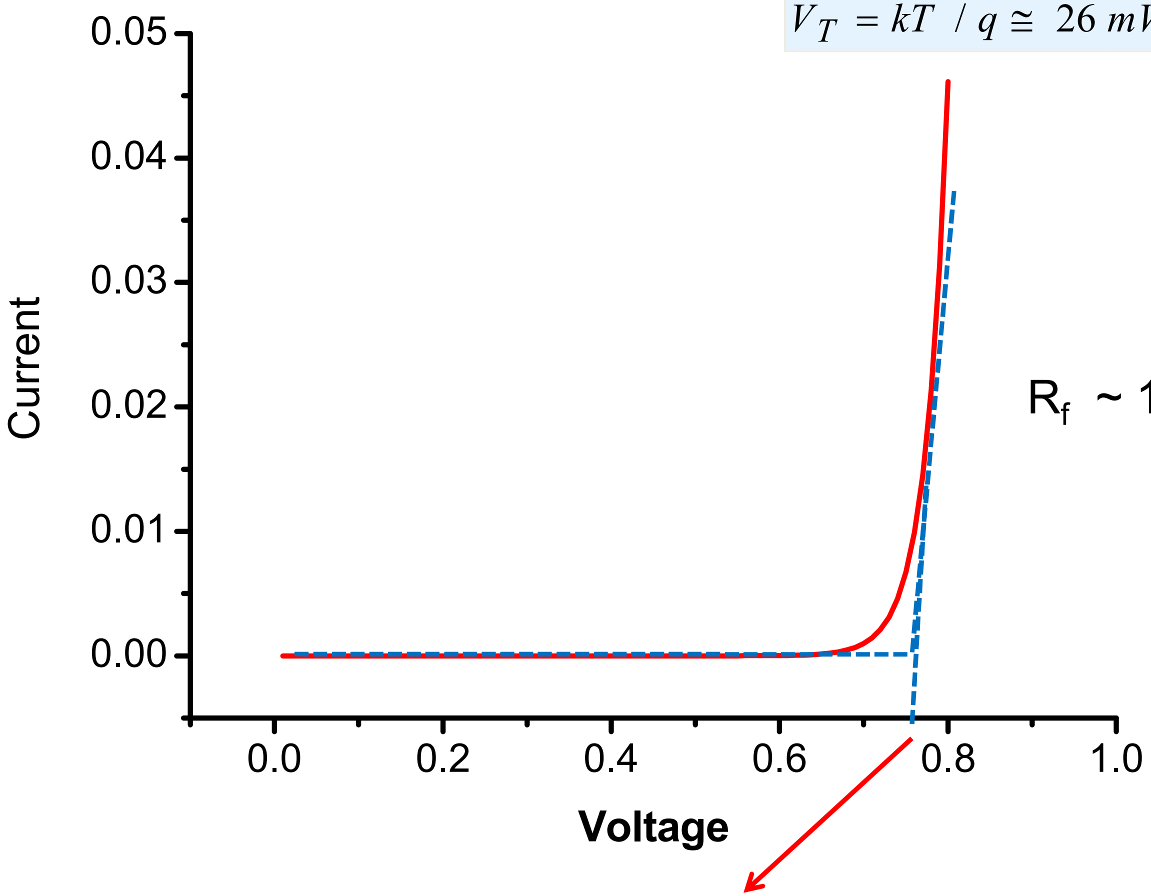


V_γ is called cut-in or turn-on voltage and depends on nature of diode and range of current considered

$$I = I_S \times \{\exp(\frac{V}{V_T}) - 1\}$$

$$I_S = 2 \times 10^{-15}\ A$$

$$V_T = kT / q \cong 26\ mV \text{ at } T = 300\text{K}$$



$R_f \sim 1.4\Omega$

$V_\gamma = 0.75V$

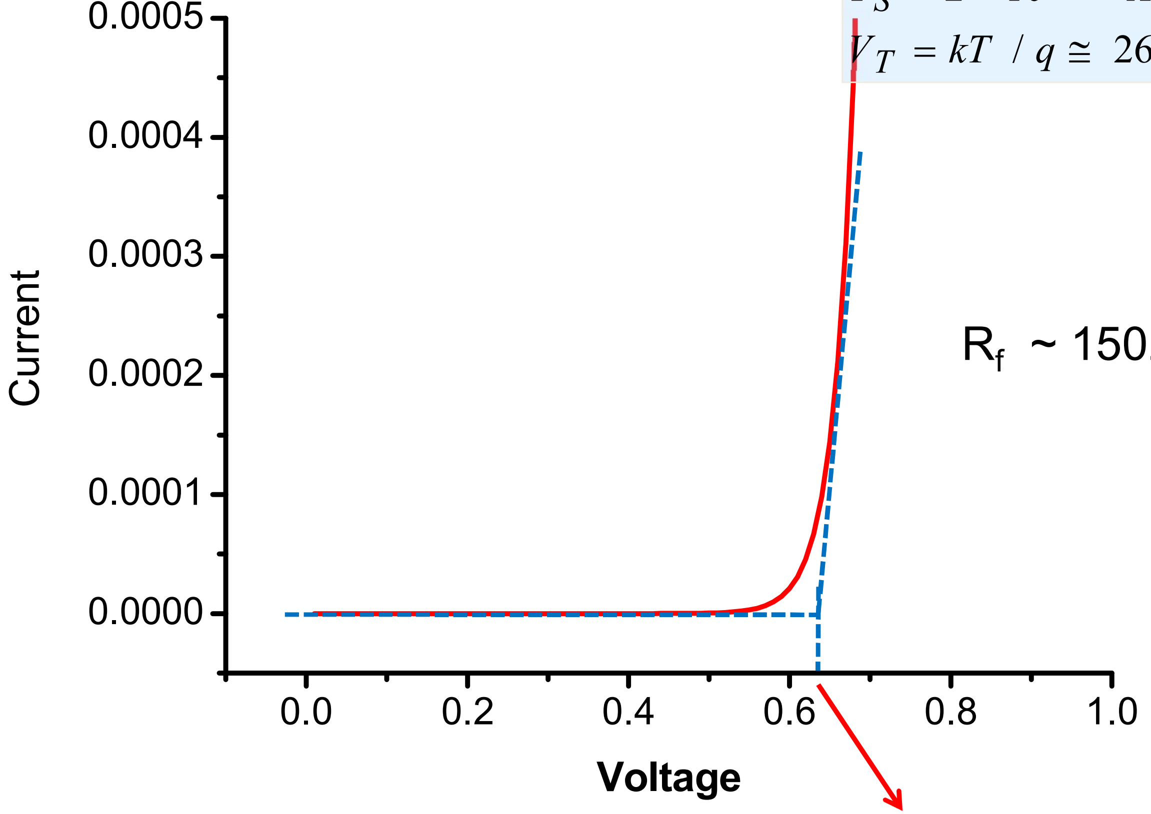
Current ~ 25mA

Current ~ 0.25mA

$$I = I_S \times \{\exp(\frac{V}{V_T}) - 1\}$$

$$I_S = 2 \times 10^{-15}\ A$$

$$V_T = kT / q \cong 26\ mV \text{ at } T = 300K$$

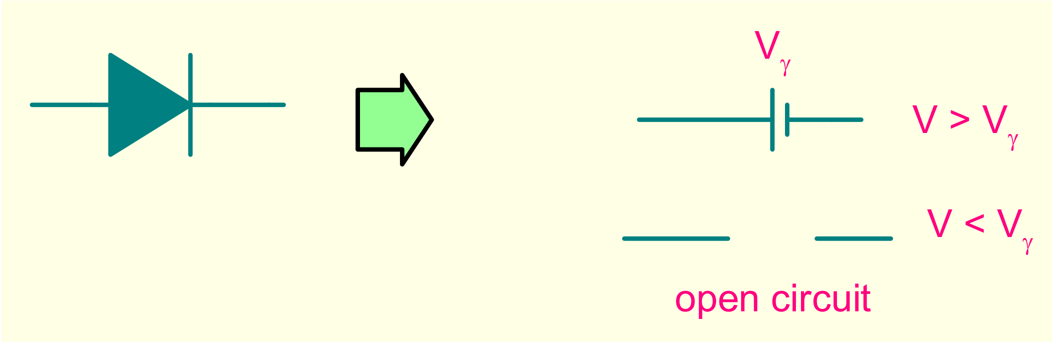


R_f ~ 150Ω

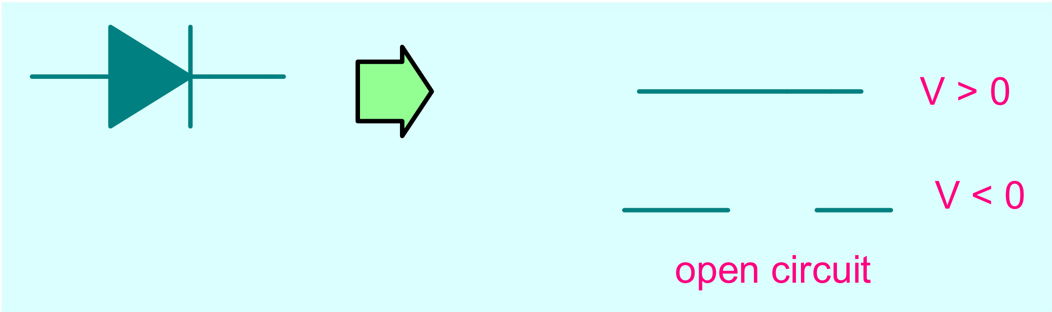
V_γ = 0.63V

For most of our analysis, we will take V_γ = 0.7V and r_f ~10Ω

Even Simpler Diode Models

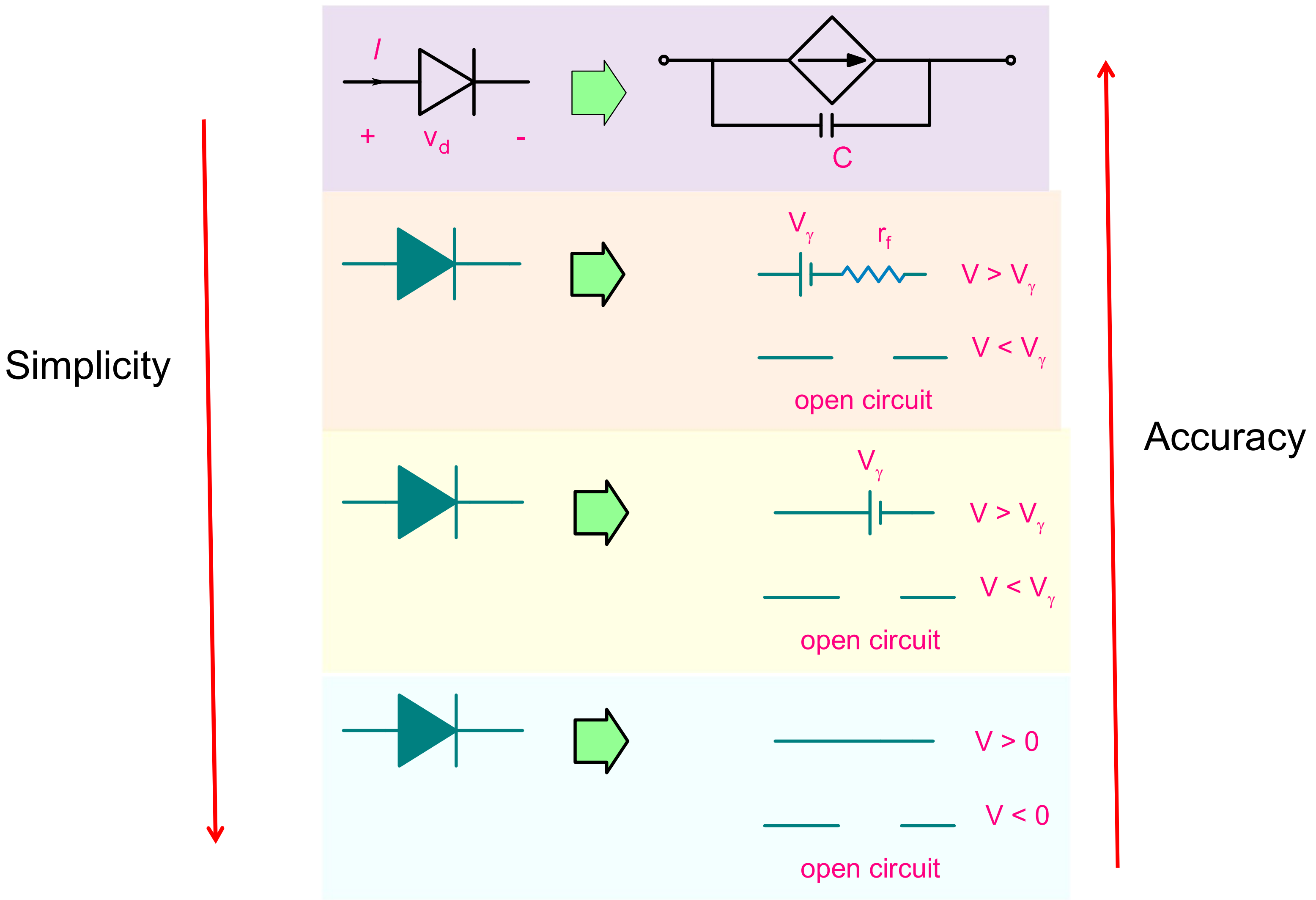


Ideal diode model

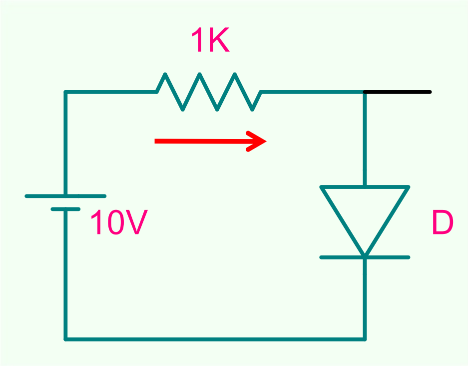


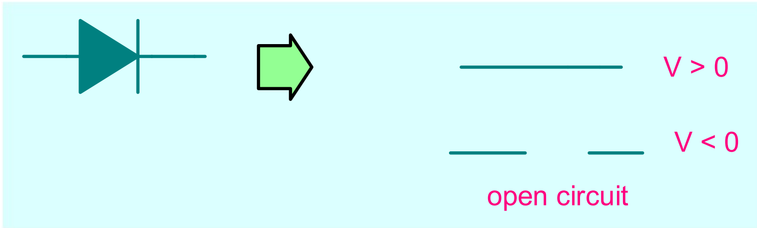
Diode Models

$$I = I_S \times \{\exp(\frac{v_d}{V_T}) - 1\}$$



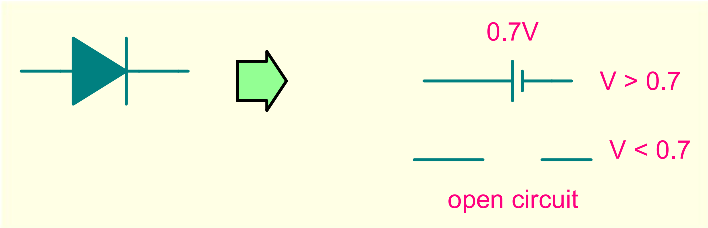
Use the simplest model that will yield results with desired accuracy





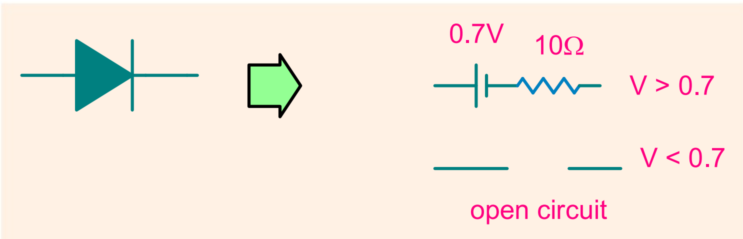
$$I = 10/10^3 = 10mA$$

8.2%



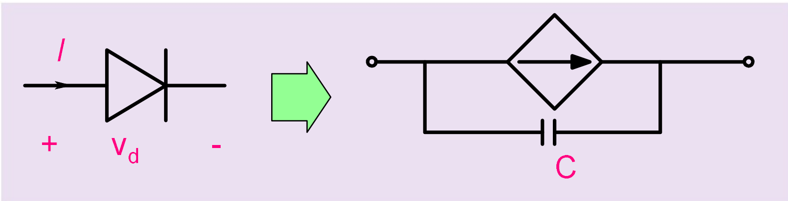
$$I = (10 - 0.7)/10^3 = 9.3mA$$

0.65%



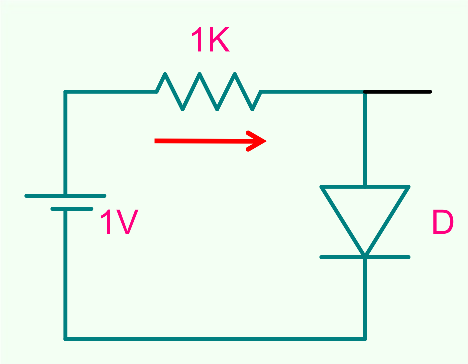
$$I = (10 - 0.7)/(10^3 + 10) = 9.208mA$$

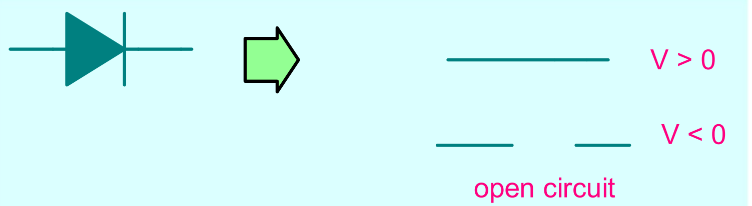
-0.34%



$$I = 9.24mA$$

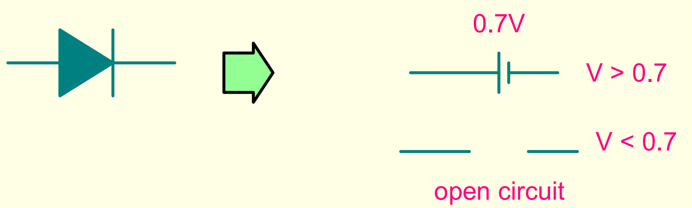
Use the simplest model that will yield results with desired accuracy





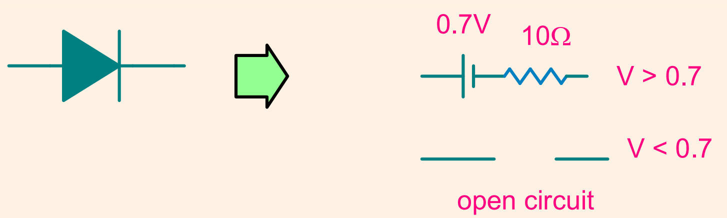
$$I = 1/10^3 = 1mA$$

~200%



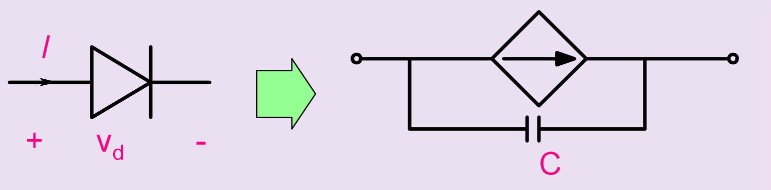
$$I = (1-0.7)/10^3 = 0.3mA$$

-8.8%



$$I = (1-0.7)/(10^3+10) = 0.297mA$$

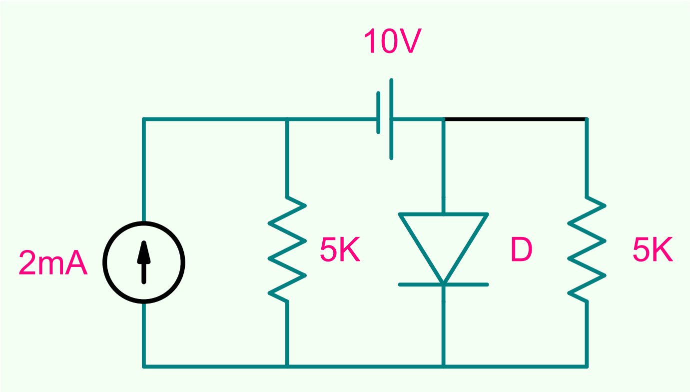
-9.7%



$$I = 0.329mA$$

Example

Find the current through the diode using ideal diode model



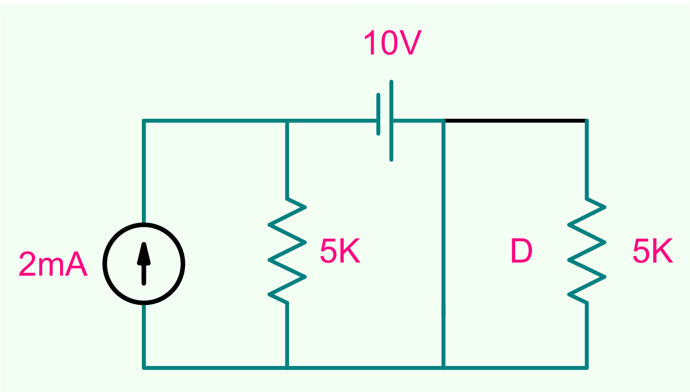
If it is not evident whether diode is forward or reverse biased then we can assume that it is forward biased, carry out analysis and then check if current through the diode is in appropriate direction. If not, diode is reverse biased and we carry out analysis again.

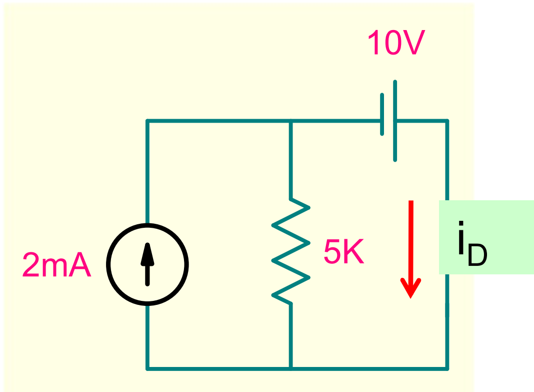
$$-2mA + \frac{-10}{5K} + i_D = 0$$

Assume forward bias

$$i_D = 4mA$$

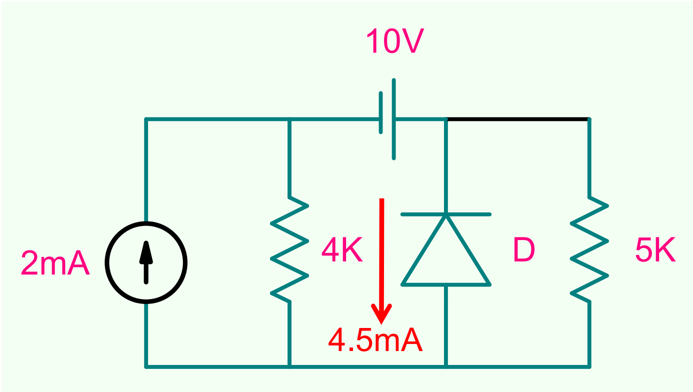
Current is positive, so our assumption is correct





Example

Find the current through the 5K resistor using ideal diode model

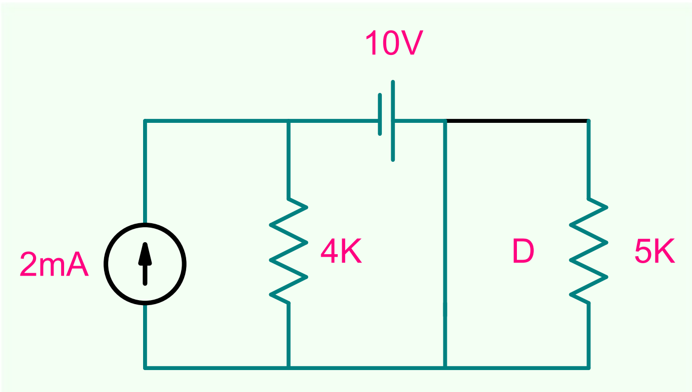


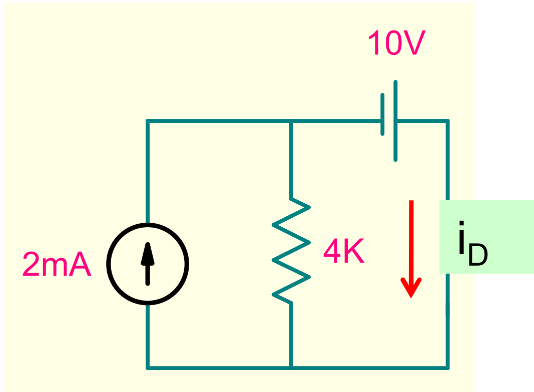
$$-2mA + \frac{-10}{4K} + i_D = 0$$

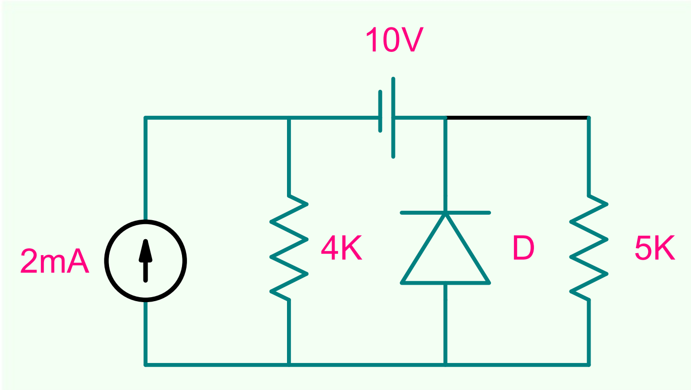
$$i_D = 4.5mA$$

Assume forward bias

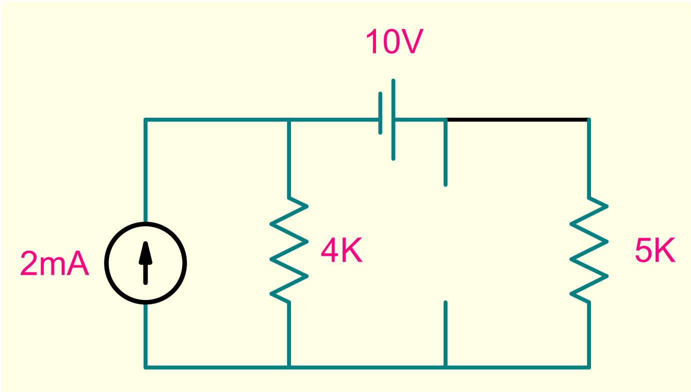
But this cannot be, so our assumption is incorrect



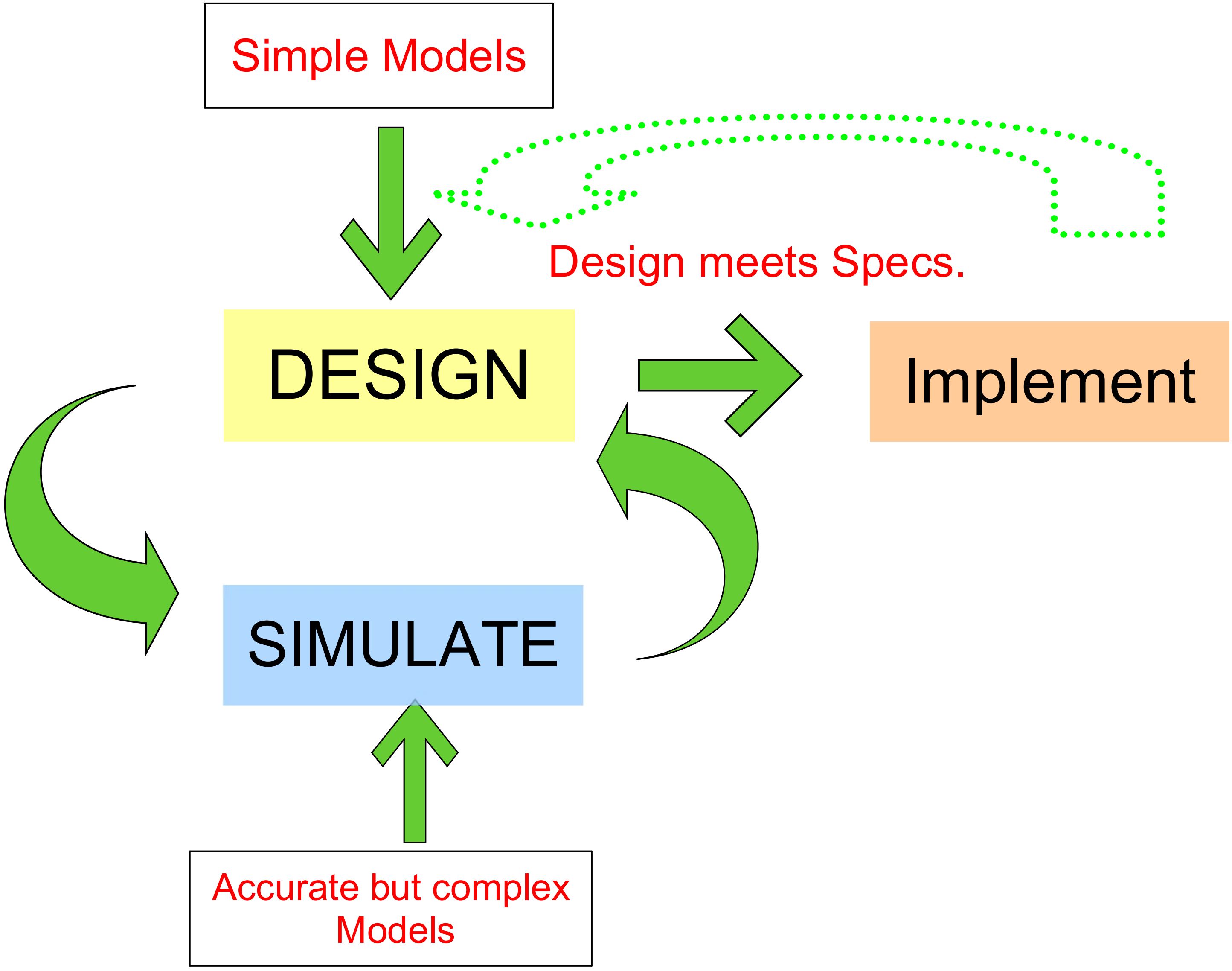




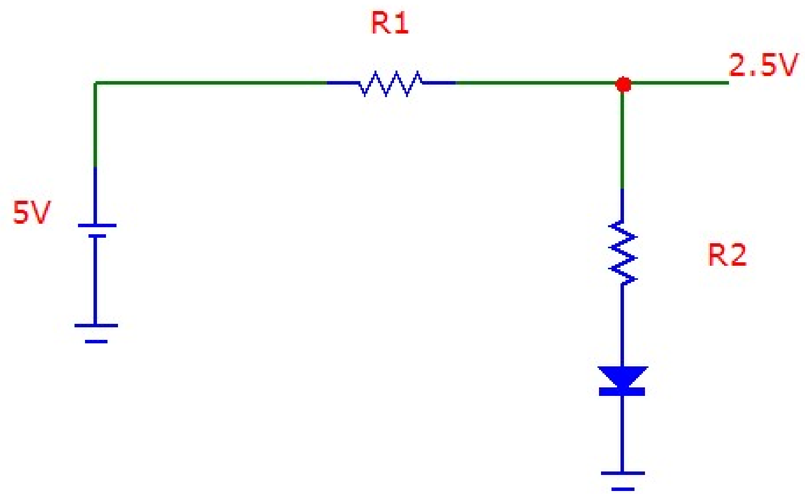
Assume reverse bias

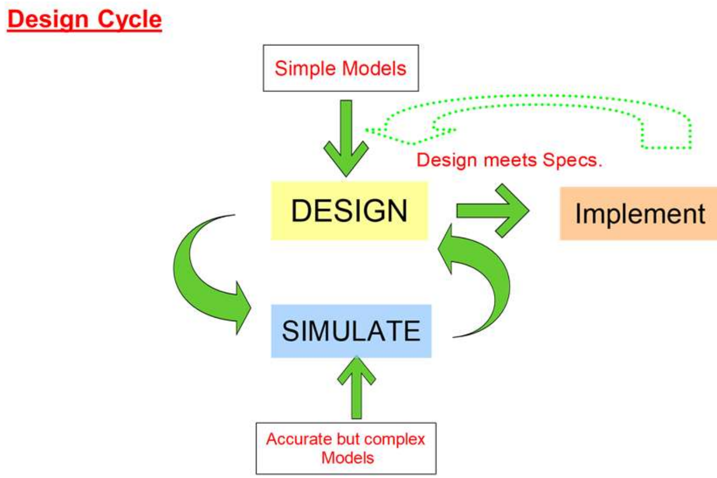


Design Cycle

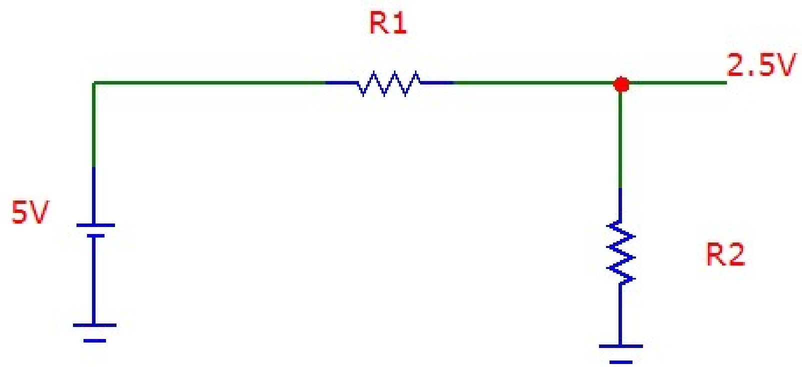


Design the following circuit





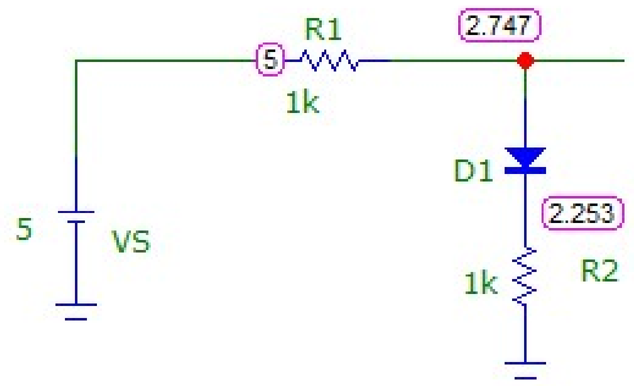
Assuming ideal diode model



$R_1 = R_2 = 1K$

Carry out simulations to fine tune the design

Initial design



Final Design